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Acting and Anticipating: Impact of Outcome-Compatible Distractor Depends on Response Selection Efficiency

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Action selection is thought to involve selection of the action's sensory outcomes. This notion is supported when encountering a distractor that resembles a learned response–outcome biases response selection. Some evidence, however, suggests that a larger contribution of stimulus-based response selection leaves little role for outcome-based selection, especially in forced-choice tasks with easily identifiable target stimuli. In the present study, we asked whether the contribution of outcome-based selection depends on the ease and efficiency of stimulus-based selection. If so, then efficient stimulus-based response selection should reduce the impact of an irrelevant distractor that resemble a response–outcome. We manipulated efficiency of stimulus-based selection by varying the spatial relationship between stimulus and response (Experiment 1) and by varying stimulus discriminability (Experiments 2). We hypothesized that with efficient stimulus-based selection, outcome-based processes will play a weaker role in response selection, and performance will be less susceptible to outcome-compatible or -incompatible distractors. By contrast, when stimulus-based selection is relatively inefficient, outcome-based processes will play a stronger role in response selection, and performance should be more susceptible to outcome-compatible or -incompatible distractors. Confirming our predictions, our results showed stronger impact of the distractors when stimulus-based response selection was relatively inefficient. Finally, results of a control experiment (Experiment 3) suggested that learning the consistent response–outcome mapping is necessary for obtaining the effect of these distractors. We conclude that outcome-based processes do contribute to response selection in forced-choice tasks, and that this contribution varies with the efficiency of stimulus-based response selection.

Keywords: action selection, associative learning, ideomotor theory, theory of event coding

The present article is concerned with the theoretical distinction between stimulus-based and outcome-based selection of action. Stimulus-based action is considered to be a response to some sensory stimulus that is present during action selection, while outcome-based action involves an intention to bring about a sensory outcome that is absent during selection (Hommel, 2013; Shin, Proctor, & Capaldi, 2010). One approach has viewed stimulus- and outcome-based actions as two aspects of a single process (Haggard, 2008; Krieghoff, Waszak, Prinz, & Brass, 2011), while another approach has viewed them as two antagonistic modes of action control, only one of which can dictate selection at any given time (Herwig, Prinz, & Waszak, 2007; Obhi & Haggard, 2004; Pfister, Heinemann, Kiesel, Thomaschke, & Janczyk, 2012; Waszak et al., 2005). In the present article, we argue that although stimulus- and outcome-based processes can concurrently contribute to action selection, the contribution of outcome-based selection varies depending on the ease and efficiency of stimulus-based selection.

Outcome-based selection of action is central to the ideomotor theory, which posits that learned sensory consequences of an action are essential to the action's representation (Hommel, 2013; Shin et al., 2010). When a motor movement causes a sensory feature, the two bind as features of a single sensorimotor event (Dutzi & Hommel, 2009; Janczyk, Heinemann, & Pfister, 2012). Repeated binding of the two features results in long-term bidirectional association between the motor feature and the sensory feature, in the sense that activation of the sensory outcomes can activate the corresponding action (e.g., Elsner & Hommel, 2001). Indeed, according to the ideomotor theory, activating the associated sensory outcome is necessary for selecting an action (i.e., outcome-based selection).

Support for the role of outcome-based action selection was reported by Kunde (2001), who compared performance across two conditions that differed in terms of the spatial compatibility between keypress responses and sensory response outcomes.

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Response–outcome (R-O) compatibility was constant in each block, and the two conditions were identical in terms of stimulus–responses (S-R) assignment. Results showed better performance in the R-O compatible condition compared to the incompatible condition, suggesting that selecting actions automatically activated the learned sensory outcomes (see also, Koch & Kunde, 2002; Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014; Pfister, Kiesel, & Melcher, 2010). Follow-up experiments showed the R-O compatibility effect requires the participants' intention to bring about the sensory outcome. That is, the same conditions might fail to produce the R-O compatibility effect if participants do not intend the sensory outcome (e.g., Ansorge, 2002; Zwosta, Ruge, & Wolfensteller, 2013).

Additional empirical support for outcome-based action selection comes from demonstrating performance sensitivity to a stimulus that resembles a learned action-outcome. These studies typically consist of two phases: an acquisition phase, in which novel R-O associations are learned, and a test phase, in which outcome-resembling stimuli are presented to induce their associated response (e.g., Hommel, 1996). In a study by Elsner and Hommel (2001) participants learned that two keypress responses each produced a tone with a distinct pitch. In the test phase, the tones were used as target stimuli. Participants were divided into two groups. For one group, tones were assigned to the responses that produced them during the acquisition phase (stimulus–outcome [S-O] compatible), while for the other group stimuli were assigned to the responses that did not produce them (S-O incompatible). Participants in the compatible condition showed better performance compared to participants in the incompatible condition (see also, Hughes, Schütz-Bosbach, & Waszak, 2011; Wolfensteller & Ruge, 2011; Ziessler, Nattkemper, & Frensch, 2004; Ziessler & Nattkemper, 2011; Ziessler, Nattkemper, & Vogt, 2012). Thus, perceiving a learned action-outcome can bias action selection.

Modifying the design of Elsner and Hommel (2001, Experiment 1), Herwig et al. (2007) manipulated whether responses in the acquisition phase were forced-choice (i.e., determined by a target stimulus) or free-choice (chosen by participants). They found that performance in the test phase benefited from S-O compatibility only after free-choice acquisition, whereas no compatibility effect was observed after forced-choice acquisition. These results suggest that when response selection is stimulus-based, contribution of outcome-based processes is reduced (see also, Herwig & Waszak, 2009; Pfister, Kiesel, & Hoffmann, 2011). It is worth mentioning, however, that Herwig et al. did find a compatibility effect with forced-choice acquisition, although only in performance accuracy of their second experiment (p. 1547),[1] which to some degree works against a strong difference between forced- and free-choice conditions.

The findings of Herwig et al. (2007) are consistent with the view that stimulus-based and outcome-based action selection represent distinct mechanisms whose relative contributions vary with context (Obhi & Haggard, 2004; Shin & Proctor, 2012; Waszak et al., 2005). The authors speculated that outcome-based processes might have little or no effect when a response can be efficiently selected based on the target stimulus, which is often the case in forced-choice tasks with a small set of highly discriminable targets. This possibility, which speaks directly to the ideomotor theory of action, has not been directly tested, and is the question we address in the present study.

In a set of forced-choice tasks, we manipulated stimulus-based response selection efficiency. We examined the contribution of outcome-based processing, by examining the degree to which a distractor that resembled a learned R-O can influence performance (Elsner & Hommel, 2001, 2004; Gozli, Goodhew, Moskowitz, & Pratt, 2013; Hommel, 2004; Herwig et al., 2007; Ziessler & Nattkemper, 2011; Ziessler et al., 2012). With highly efficient stimulus-based selection, we predicted a relatively weaker effect of such distractors. On the other hand, with lower efficiency of stimulus-based response selection, we predicted a larger effect of such distractors. Should this occur, it would confirm that outcome-based processes do play a role in forced-choice tasks, and that their relative contribution depends partly on the efficiency of stimulus-based processes.

To manipulate the efficiency of stimulus-based processes, we employed two different methods. In Experiment 1, we manipulated S-R spatial relationship in a localization task. We assumed that direct spatial mapping between the stimulus set and the response set (i.e., left and right response keys, respectively, assigned to left and right targets) leads to more efficient stimulus-based selection, compared to inverse mapping (i.e., left and right response keys, respectively, assigned to right and left targets; Fitts & Seeger, 1953). If inefficient stimulus-based selection increases the contribution of the outcome-based selection processes, then response selection with inverse S-R spatial mapping should be more sensitive to an irrelevant stimulus that resembles a response outcome (i.e., larger S-O compatibility). By contrast, in the direct S-R spatial mapping, response selection should be less sensitive to irrelevant feature that resembles a response outcome (i.e., smaller S-O compatibility).

In Experiment 2, we manipulated stimulus discriminability in a visual discrimination task. There are two ways to characterize this manipulation. First, if we presuppose discrete processing stages (Sternberg, 1969, 1998; also, Sanders, 1990; Miller, 1988; Verwey, Shea, & Wright, 2015), then manipulating stimulus discriminability is unlikely to affect response selection. The second way to characterize the impact of stimulus discriminability, is based on the assumption of automatic S-R translation (Hommel, 1997, 1998a; MacLeod & Dunbar, 1988; Turvey, 1973). According to this view, higher stimulus discriminability results, not only in higher certainty in perceptual discrimination, but in stronger activation of the correct response (e.g., Berlyne, 1957; Hommel, 2000). That is, maintaining the S-R translation task rule affects how stimuli are encoded, which in turn results in each stimulus automatically activating its corresponding response (e.g., Ansorge & Wühr, 2004). Although we favor the second interpretation, our view is also consistent with a stage model in which stimulus identification and response activation (i.e., S-R translation) both occur prior to the response-selection stage (Hommel, 1998a; Miller, 1988; Verwey et al., 2015).

Thus, in Experiment 1, the correct response on each trial would be more strongly activated with direct spatial S-R mapping, compared to the inverse mapping. Similarly, in Experiment 2, we

[1] This is important in the context of the present study, because our critical findings (from Experiments 1 and 2) also appear in accuracy data. We thank Markus Janczyk for bringing this aspect of the Herwig et al. (2007) study to our attention.

reason that the correct response is more strongly activated when stimuli are easier to discriminate, compared to when they are difficult to discriminate (Proctor & Cho, 2006; Proctor & Reeve, 1985). In both experiments, we expected to find evidence for higher contribution of outcome-based processes when stimulus-based selection is relatively inefficient, that is when the correct response is less strongly activated based on the stimulus.

Our experiments consisted of an acquisition phase and a test phase. In the acquisition phase, participants responded to a laterally presented target stimulus, and each response caused a centrally presented visual outcome. In the test phase, each target stimulus was presented together with a compatible (activating the same response) or incompatible (activating the alternative response) action outcome. We assumed the S-O compatibility effect to reflect the contribution of outcome-based selection processes, because it is the outcome-based selection processes that render observers sensitive to an irrelevant feature that resembles a learned R-O (e.g., Elsner & Hommel, 2001, 2004; Hommel & Elsner, 2009). By contrast, a smaller S-O compatibility effect would indicate the dominance of stimulus-based selection and lower sensitivity to sensory outcomes, suggesting weaker contribution of outcome-based response selection processes (e.g., Herwig et al., 2007; Herwig & Waszak, 2009). Because in the present study we use the effectiveness of a distractor to infer the relative contribution of stimulus- and outcome-based processes using, our hypothesis fits the view that the difference between the two modes of action is due to differences in perceptual processing (e.g., Janczyk, Dambacher, Bieleke, & Gollwitzer, 2015; Janczyk, Nolden, & Jolicoeur, 2015).

To foreshadow the findings, we found that inefficient stimulus-based action selection increased observer's sensitivity to the distractor feature that resembles a learned R-O (i.e., S-O compatibility effects), suggesting that outcome-based selection varies with the efficiency of stimulus-based selection. Specifically, Experiment 1 found that the inverse spatial S-R mapping increased the S-O compatibility effect, relative to the direct S-R mapping. Similarly, Experiment 2 found that low discriminability of targets increased S-O compatibility, relative to high discriminability. Furthermore, Experiment 2 suggested that stimulus-based selection efficiency primarily impacts the usage of response outcomes, and not their learning. Finally, Experiment 3 supported the assumption that the response (i.e., consistent S-R and R-O mapping) plays a role in obtaining the S-O compatibility effect, by showing the absence of the S-O compatibility effect when participants are merely exposed to implicit S-O covariation.

Experiment 1

This experiment consisted of a two-choice localization task (left vs. right). One group of the participants performed in the direct mapping condition, which means they responded to stimulus location with the spatially corresponding key (e.g., left key for left target). The other group performed in the inverse mapping condition, which means they responded to stimulus location with the noncorresponding key (e.g., right key for left target). Both groups performed in an acquisition phase and a test phase. During both phases, each response was followed immediately by a visual action outcome, which consisted of a chromatic change at the center of the display. In the test phase, the target stimuli were presented in colors that could be compatible or incompatible with the outcome of the correct response. We predicted that the impact of this irrelevant color feature would be larger in the inverse mapping condition, compared to the direct mapping condition, reflecting a relatively higher contribution of outcome-based selection.

Method

Participants. Forty-six University of Toronto undergraduate students (mean age: 19.6; 28 females) gave informed consent and took part in this experiment in exchange for course credit. They were randomly assigned to one of the two S-R mapping conditions (direct vs. inverse), resulting in 23 participants in each condition.

Apparatus and stimuli. The experiment was run in Matlab (MathWorks, Natick, MA), using the Psychophysics toolbox (Brainard, 1997; Pelli, 1997; Version 3.0.8) on Windows-run PCs. Participants performed the task in dimly lit rooms. Stimuli were presented on 19" CRT monitors set at 1024 × 768 resolution and 85 Hz refresh rate. Using a chin/head-rest, distance from the display was fixed at about 45 cm.

The display structure and the sequence of events are shown in Figure 1. All stimuli appeared against a black background. Three horizontally aligned squares (size = 2.4° × 2.4°) functioned as placeholders for targets and outcomes. The potential locations for the target stimuli were the lateral squares, with centers that deviated by 6° of visual angle from the center. The central square served as the location of the response outcomes. Whereas the target stimulus during the acquisition phase consisted only of increasing frame thickness of one of the lateral squares (from .08° to .24°), in the test phase it consisted of both a change in thickness and a change of color. An action-outcome, in both phases of the experiment, consisted of a change in the thickness and color of the central placeholder.

Procedure and instructions. Each trial began with the presentation of the three placeholders. After a random delay (chosen from the uniformly probable interval: 500–1,000 ms), the target stimulus appeared at the left or right placeholder. We chose a random delay between trial onset and target onset in order to reduce temporal expectations regarding the target, and in an attempt to highlight the temporal contiguity between response and outcome (i.e., to highlight that, regardless of when the stimulus appears, and when the response is performed, the outcome always immediately follows the response). In the direct-mapping condition, participants were instructed to press a spatially corresponding key in response to the target (*Z* key for left; *?/* key for right on a QWERTY keyboard). We instructed each participant, "if the left box lights up, press the left-hand key and if the right box lights up, press the right-hand key." In the inverse-mapping condition, they were instructed to press the noncorresponding key (i.e., left-hand key in response to a target on the right side, and vice versa). Response times were measured relative to the onset of the target stimulus. Immediately after a correct response (more precisely, this took 10–20 ms, depending on the current CPU load), the R-O appeared at the central placeholder, remaining on display 200 ms. The yellow R-O resulted from a left key-press, and the blue outcome resulted from a right key-press. Color outcomes only followed correct responses. After an incorrect keypress, participants immediately received a visual feedback screen (*MISTAKE*), which remained on display for 2,000 ms.

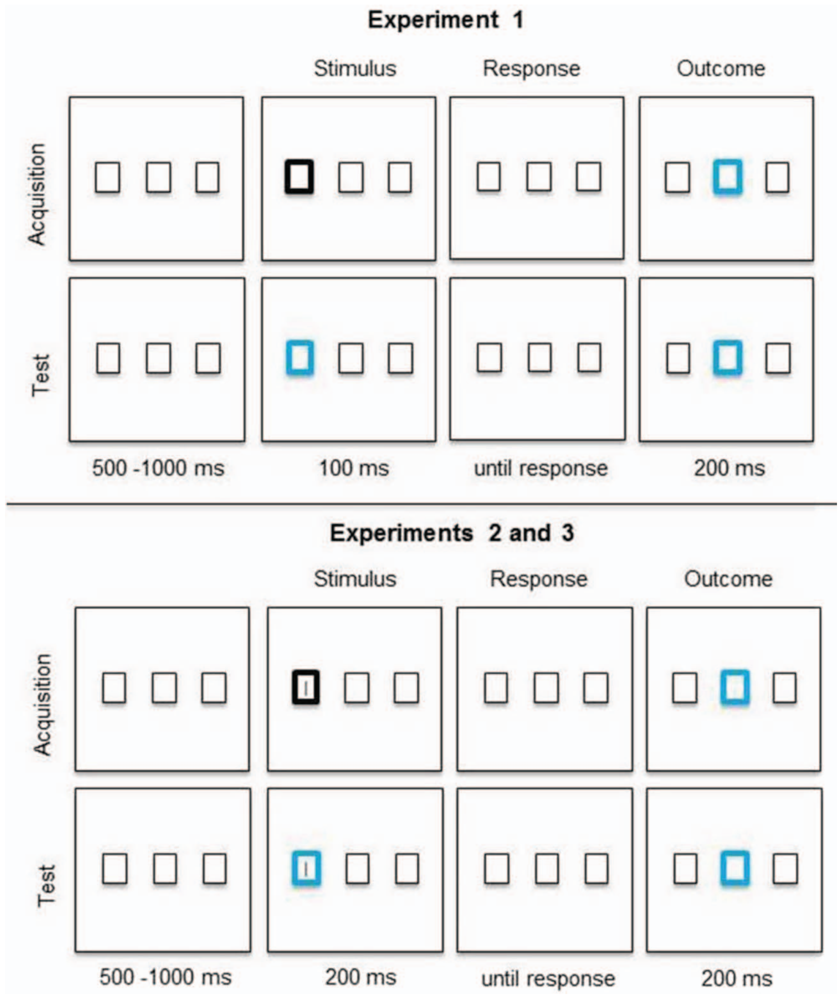

Figure 1. Sequence of events on a sample trial of the acquisition and test phase of the present experiments. Experiment 1 required target localization (left vs. right) using direct or inverse key–target spatial mapping. Experiment 2 required judgment of target length (short vs. long) in two different conditions of low and high perceptual discriminability. See the online article for the color version of this figure.

We should note that we informed participants about the link between their responses and response outcomes (colors). Specifically, without telling them about the exact key-color mapping, we informed each participant that "every time you press a key correctly, your keypress will immediately change the color of the middle box" (see Figure 1). Although these instructions do draw the participants' attention to the relationship between responses and outcomes, they nonetheless differ from instructions that frame the responses in terms of production of the outcome (i.e., "if you see the left target, then change the color of the middle box to yellow"; cf. Ansorge, 2002; Hommel, 1993; Zwosta et al., 2013). Finally, we informed participants that the color of the target stimuli, in the test phase, were irrelevant to the task and responses should be made only based on stimulus location. Because actual outcomes were presented throughout both phases of the experiment, S-O compatibility did not only mean a match between the correct response and the irrelevant feature of the target, but also a match between the irrelevant feature of the target stimulus and the outcome feature.

Design. Each participant was randomly assigned to either the direct or the inverse S-R mapping conditions, and completed a single experimental session. The acquisition phase consisted of 120 trials, followed by the test phase that consisted of 80 trials. Stimulus location (left vs. right) and S-O compatibility were both randomized and manipulated independently.

Results and Discussion

Acquisition. Performance in the acquisition phase was highly accurate in both the direct (M ± *SE* = 98% ± .5%) and the inverse (97% ± .5%) S-R mapping conditions, although a one-tailed[2] *t* test revealed an advantage for the direct mapping, $t(44) = 1.81$, $SE = .01$, $p = .038$. Furthermore, responses were faster in the direct (344 ± 9

[2] One-tailed *t* tests were used here because of the highly predictably advantage of direct S-R mapping over inverse S-R mapping. The remaining *t* tests in the present study are all two-tailed.

ms) condition compared to the inverse condition (467 ± 19 ms, one-tailed $t(44) = 5.89$, $SE = 21$, $p < .001$).

Test. Accuracy data were submitted to a 2 × 2 mixed analysis of variance (ANOVA) with S-R mapping (direct vs. inverse) and S-O compatibility, respectively, as the between-subjects and the within-subjects factors (see Figure 2). This analysis showed neither a main effect of S-R mapping, $F(1, 44) = .25$, $p = .62$, $\eta_p^2 = .01$, nor a main effect of compatibility, $F(1, 44) = 1.99$, $p = .16$, $\eta_p^2 = .04$. However, a significant interaction was found, $F(1, 44) = 7.67$, $p = .008$, $\eta_p^2 = .15$. This interaction was driven by a reliable S-O compatibility effect in the inverse mapping condition, 1.81% ± .64%, $t(22) = 2.97$, $SE = .01$, $p = .007$, Cohen's $d = .60$, but not in the direct condition, −.55% ± .56%, $t(22) = 1.12$, $SE = .005$, $p = .27$, Cohen's $d = -.21$.

Response time (RT) data, after excluding incorrect responses and responses that were over 2.5 *SD* above or below the mean, were also submitted to the same ANOVA (see Figure 2). This analysis revealed main effects of S-R mapping, $F(1, 44) = 28.29$, $p < .001$, $\eta_p^2 = .391$, and S-O compatibility, $F(1, 44) = 4.17$, $p = .047$, $\eta_p^2 = .09$. The main effect of S-R mapping was due to shorter RTs in the direct mapping condition (344 ± 17 ms) compared to the inverse mapping condition (470 ± 17 ms). The main effect of S-O compatibility was due to shorter RTs on compatible trials (403 ± 14 ms), compared to incompatible trials (410 ± 16 ms). Critically, the two-way interaction was not significant in the RT findings, $F(1, 44) = 1.06$, $p = .31$, $\eta_p^2 = .02$. Because the interaction is crucial, we also report the post hoc *t* tests for both groups. For both the direct S-R mapping, $t(22) = 1.57$, $SE = 2.35$, $p = .132$, Cohen's $d = .33$, and the inverse S-R mapping, $t(22) = 1.62$, $SE = 6.88$, $p = .119$, Cohen's $d = .34$, the tests did not yield statistical significance. Based on the similarity of effects on RT across the two S-R conditions, the interaction in accuracy data seems not to reflect a speed–accuracy trade-off.

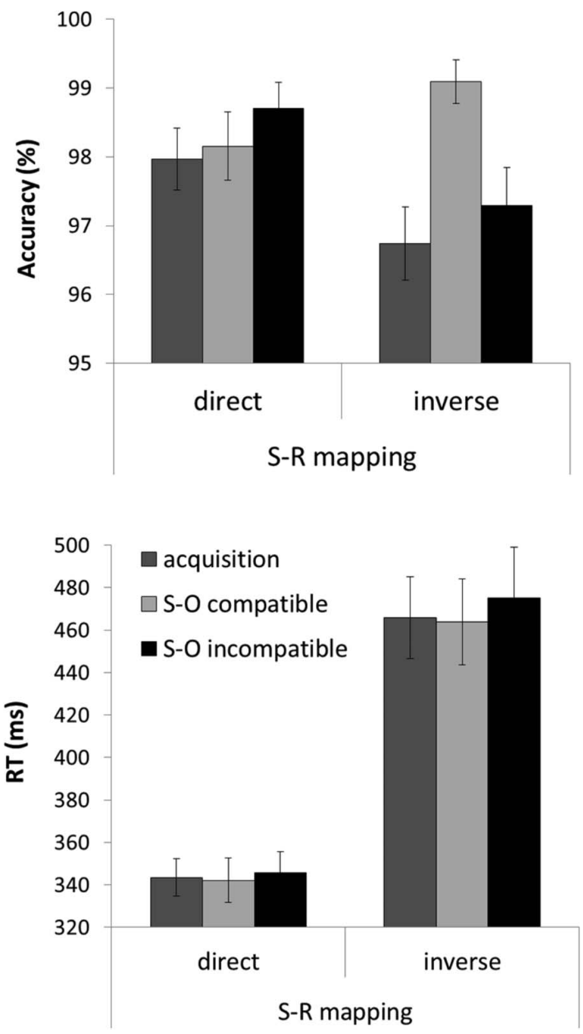

Figure 2. Performance in Experiment 1, graphed as a function of stimulus–response spatial mapping and stimulus–outcome compatibility. Error bars indicate standard errors.

In sum, consistent with our prediction, an interaction between S-R spatial mapping and S-O compatibility was observed in performance accuracy. The S-O compatibility effect was larger in the inverse mapping condition, compared to the direct mapping. This interaction suggests that the inverse S-R mapping increased participants' sensitivity to sensory outcomes such that the irrelevant colors accompanying target stimuli exerted a stronger effect on response selection. This supports the proposal that inefficiency in stimulus-based selection can increase the contribution of outcome-based selection of a response. To further test this idea, we conducted Experiment 2, using a different way to manipulate stimulus-based selection efficiency.

Experiment 2

This experiment consisted of a visual orienting-discrimination task, in which the target (a vertical line) could appear inside a peripheral (left or right) placeholder. Participants were instructed to respond using a key-press (left vs. right) to the length of the target line ("short" vs. "long"), regardless of its location. Critically, the target stimuli were easy or hard to discriminate, depending on the similarity between the "short" and "long" target lines.

We aimed to answer two questions in this experiment. First, as in Experiment 1, we asked whether reducing stimulus-based response selection efficiency can increase the contribution of outcome-based selection. If so, then participants who respond to relatively less discriminable stimuli would be more susceptible to distractors that resemble learned R-O, relative to participants who respond to highly discriminable stimuli. Thus, we predicted larger S-O compatibility effect with low stimulus discriminability and smaller S-O compatibility effect with high discriminability.

Second, we asked whether the difference between easy and difficult stimulus conditions depends primarily on the learning or the use of R-O associations. To disentangle the learning and the use of R-O associations, we varied stimulus discriminability orthogonally during the acquisition phase and the test phase. If stimulus discriminability changes the learning of outcomes, then discriminability during the acquisition phase should be crucial. By contrast, if stimulus discriminability changes the use of outcomes in selection, then discriminability in the test phase should be crucial. We divided the participants into four groups. One group performed both phases with highly discriminable target stimuli. Another group performed both phases with less discriminable stimuli. The remaining two groups performed one phase with highly discriminable stimuli and the other phase with less discriminable stimuli.[3]

A study by Pfister et al. (2011) supports the notion that efficient stimulus-based response selection does not reduce R-O learning, but it reduces the use of R-O associations. Pfister et al. divided their participants into four groups, orthogonally manipulating task type (free-choice vs. forced-choice) during the acquisition phase and the test phase. They found reliable S-O compatibility when the test phase required free-choice responses, regardless of type of task in the acquisition phase. The authors concluded that R-O learning can take place regardless of whether responses are selected in a stimulus-based or outcome-based manner, but that the learned associations are more robustly used in a free-choice task.

Our prediction, therefore, was twofold. First, in line with Experiment 1, we predicted larger S-O compatibility effect with less discriminable stimuli. Second, in line with the findings of Pfister et al. (2011), we predicted that stimulus discriminability during the test phase would be the more important predictor of the S-O compatibility effect.

Method

Participants. Ninety-two University of Toronto undergraduate students (mean age = 19.6; 63 females), gave informed consent and took part in this experiment in exchange for course credit.

Apparatus, stimuli, and procedure. These were identical to those in Experiment 1, unless stated otherwise. Each trial began with the presentation of three horizontally aligned squares. After a delay (500–1,000 ms), a vertical line appeared inside the left or right placeholder. The vertical line was the target stimulus, and participants were instructed to respond to the length of this line (*Z* key for short; *?/* key for long). In the easy conditions, the short (.3°) and the long (.8°) lines differed more from each other, compared to the hard condition (.43° and .55°, respectively). The action-outcome appeared at the central placeholder (yellow after pressing the left key; blue after pressing the right key), immediately after a correct response and remained on display for 200 ms. In the acquisition phase, the target event was a change in frame thickness of one lateral placeholders (from .08° to .24°) and the appearance of the line inside the placeholder, whereas in the test phase it consisted of the line, a change in the frame thickness, and a change in the frame color (yellow or blue). After an incorrect keypress, participants received a visual feedback screen (*MISTAKE*), which remained on display for 2,000 ms.

Design. Each participant was assigned to one of the four conditions, resulting in 23 participants in each condition. Each participant completed a single experimental session, consisting of 200 trials. The first 120 trials constituted the acquisition phase and the final 80 trials constituted the test phase. Stimulus location (left vs. right), stimulus length (short vs. long), and S-O compatibility were all randomized and manipulated independently.

Results and Discussion

Acquisition. Performance in the acquisition phase was highly accurate in the high-discriminability condition (M ± *SE* = 96% ± .6%) and significantly lower in the low-discriminability condition (82% ± 1.0%, $t(90) = 11.48$, $SE = .012$, $p < .001$). Similarly, RTs were shorter in the high-discriminability condition (543 ± 11 ms) compared to the low discriminability condition (651 ± 10 ms, $t(90) = 7.48$, $SE = 14$, $p < .001$).

Test. Accuracy data were submitted to a 2 × 2 × 2 mixed ANOVA with stimulus discriminability during acquisition (low vs. high) and stimulus discriminability during test phase (low vs. high) as the between-subjects factors, and S-O compatibility as the within-subject factor (see Figure 3). This analysis showed a main effect of compatibility, $F(1, 88) = 29.49$, $p < .001$, $\eta_p^2 = .251$, and a two-way interaction between test-phase discriminability and S-O compatibility, $F(1, 88) = 4.28$, $p = .042$, $\eta_p^2 = .046$. Neither the two-way interaction between acquisition-phase discriminability and S-O compatibility, $F(1, 88) = 1.38$, $p = .244$, $\eta_p^2 = .015$, nor the three-way interaction, $F(1, 88) = 2.07$, $p = .154$, $\eta_p^2 = .023$, reached statistical significance. Consistent with our prediction, the S-O compatibility effect on accuracy was larger with less discriminable test stimuli (7.0% ± 1.5%), compared with highly discriminable test stimuli (3.0% ± .9%). In the latter condition, the S-O compatibility effect still differed from zero (p = .002).

Response time data were submitted to the same analysis (see Figure 4), which showed a main effect of S-O compatibility, $F(1, 88) = 8.14$, $p = .005$, $\eta_p^2 = .085$, and no interaction (*F* values <1). The S-O compatibility effect on RT was found in both high discriminability (11 ± 3 ms) and low discriminability conditions (9 ± 6 ms), and the two did not statistically differ, $t(90) = .42$, $SE = 6.92$, $p = .75$. The similarity of the S-O compatibility effect across the two conditions confirms that the interaction found in accuracy data is not due to a speed–accuracy trade-off.

Spatial S-R compatibility effect. Participants in Experiment 2 were instructed to respond to stimulus length and not to stimulus location. Despite the irrelevance of stimulus location, we expected to replicate the well-known Simon effect, which is driven by the relationship between stimulus location and response location (Simon, 1969; also, Hommel, 2011; Lu & Proctor, 1995). Additionally, it would be interesting to see whether the Simon effect would interact with the S-O compatibility or stimulus discriminability. We submitted the test-phase data to a 2 × 2 × 2 mixed ANOVA with S-O compatibility and spatial S-R compatibility as the within-subject factors and stimulus discriminability as the between-subjects factor. This analysis revealed a Simon effect, for RT data: $F(1, 90) = 3.74$, $p = .056$, $\eta_p^2 = .04$; for accuracy data: $F(1, 90) = 7.54$, $p = .007$, $\eta_p^2 = .08$. Spatial S-R compatibility lead to faster (609 ± 7 ms) and more accurate responses (89% ± .7%), compared to S-R incompatibility (618 ± 7 ms; 86% ± 1%). It is important to note that the Simon effect did not interact with the S-O compatibility effect, for RT data: $F(1, 90) < 1$; for accuracy data: $F(1, 90) = 1.86$, $p = .176$, $\eta_p^2 = .02$, or with the stimulus discriminability effect, for RT data: $F(1, 90) < 1$; for accuracy data: $F(1, 90) < 1$. The absence of interaction between the S-O compatibility and the Simon effect suggests that the two irrelevant features (stimulus location and outcome-resembling color) served as independent sources of response activation (for a similar finding, see Gozli et al., 2013). The absence of interaction between stimulus discriminability and the Simon effect suggests that the

[3] The groups were not tested at the same time. Data collection for the first two groups were completed first, and we extended the design later in order to have orthogonal manipulations of stimulus discriminability in the acquisition and the test phase of the experiment.

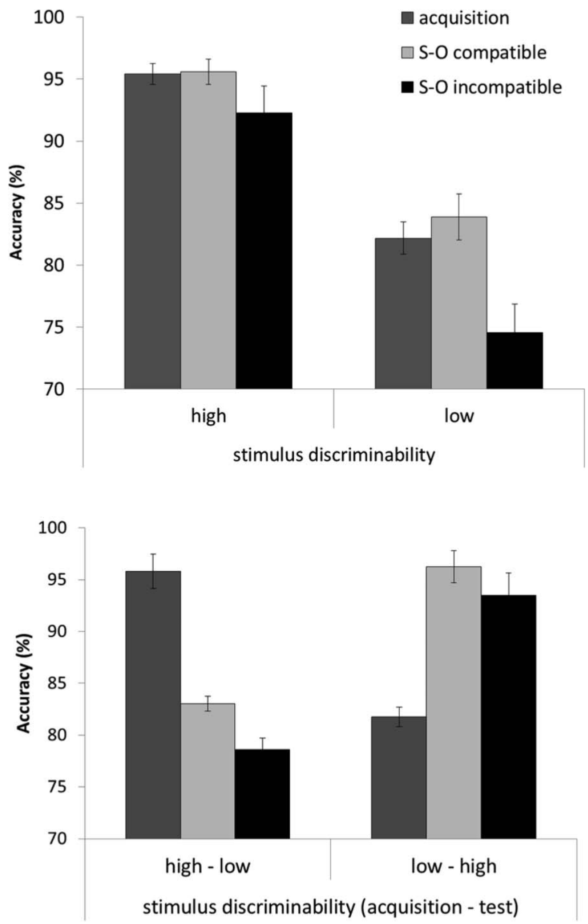

Figure 3. Performance accuracy in Experiment 2, graphed as a function of stimulus discriminability and stimulus–outcome (S-O) compatibility. Error bars indicate standard errors.

difficulty to discriminate the target feature did not increase the impact of all irrelevant features, but rather selectively increased the impact of distractors that resembled the learned visual outcomes. These findings suggest that the discriminability level, particularly during the test phase, impacts the S-O compatibility effect.

One limitation in the design of Experiments 1 and 2 prevents us from determining the precise nature of the S-O compatibility effect. We hold that this effect is driven by learned associations between responses and outcomes, and thus it reflects response activation by distractors that resemble the learned outcomes. An alternative view would be that the effect is driven by learned associations between stimuli and outcomes (i.e., length of the target lines and colors). To test this possibility we conducted Experiment 3, in which the acquisition phase maintained the S-O consistency without maintaining S-R and R-O consistency.

Experiment 3

The purpose of this experiment was to better specify the nature of the S-O compatibility effect. It is reasonable to assume that this effect is driven by associative learning between task features, because otherwise the colors will not have a systematic influence on performance. But what features exactly are associated? The first possibility is that the S-O compatibility effect might be driven by R-O associative learning, which is to say that the repeated (short-term) binding of response feature and outcomes might have resulted in (long-term) associative learning between the two features (Hommel & Elsner, 2009). Consequently, viewing an outcome-compatible distractor would activate the associated motor code, and bias participants toward selecting the response (e.g., Elsner & Hommel, 2001; Ziessler & Nattkemper, 2011).

The second possibility is that the S-O compatibility effect is driven by a perceptual associative learning between the stimulus features (line lengths) and the outcomes (colors), which is to say the repeated (short-term) binding of the two sensory features, regardless of the response, might have resulted in (long-term) associative learning between the two sensory events. Consequently, encountering one of the sensory features would activate the other associated feature. This associative activation could conceivably lead to better performance when targets accompany that feature relative to when they do not. Previous studies have found evidence of perceptual associative learning between spatiotemporally close features, even when those features are not task-relevant (e.g., Turk-Browne et al., 2010; Zhao, Al-Aidroos, &

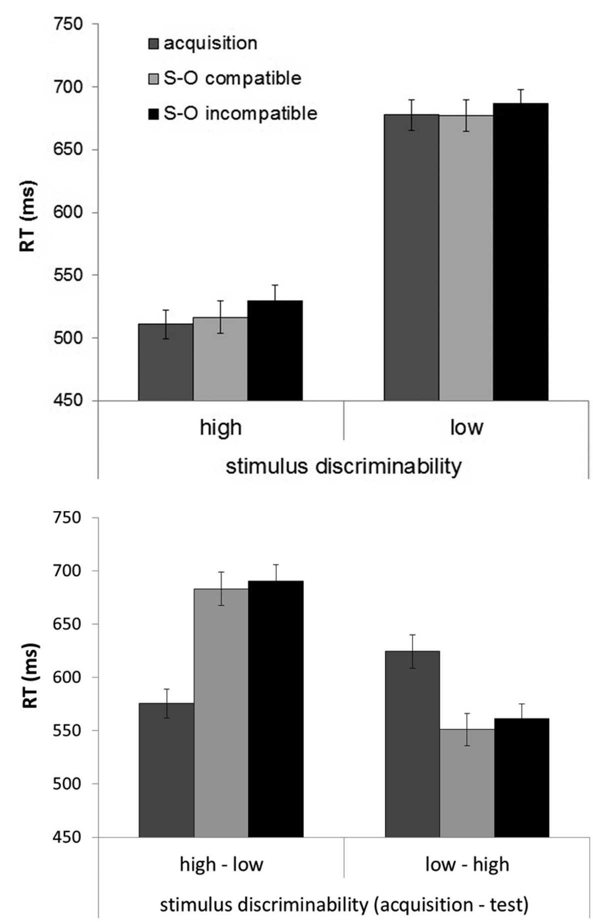

Figure 4. Performance speed in Experiment 2, graphed as a function of stimulus discriminability and stimulus–outcome (S-O) compatibility. Error bars indicate standard errors.

Turk-Browne, 2013). However, in the present study, this seems less likely because of the temporal gap between the stimulus and the outcome was much larger (>500 ms) than the gap between the response and the outcome, which increases the likelihood of R-O binding, compared to S-O binding (Elsner & Hommel, 2004; Gozli, Moskowitz, & Pratt, 2014; Zmigrod & Hommel, 2010). Nevertheless, to discriminate between these two possibilities in the present experiment, we maintain the consistent covariation between stimulus (line length) and outcome (color), during both phases of the experiment, while removing the consistency between both of those features and the response, during the acquisition phase. If R-O consistency is necessary for obtaining the S-O compatibility effect, then its removal in the acquisition phase should eliminate the S-O compatibility effect.

The task and the instructions in the test phase of Experiment 3 were identical to Experiment 2. The critical difference was in the acquisition phase, during which we used implicit S-O covariation, while using inconsistent R-O mapping. Specifically, during the acquisition phase, participants responded to the location of the target line (left vs. right) and not the length of the line. Compared to Experiment 2, in which target location was irrelevant and target length was relevant to task, in Experiment 3, target location was relevant and target length was irrelevant to task. This difference, we should emphasize, was only applied to the acquisition phase. Therefore, during acquisition, each response was equally likely to be made to a short or a long stimulus, and it was equally likely to be followed by yellow or blue outcome, because the color (outcome) was fully determined by line length. If implicit S-O covariation is sufficient for obtaining the S-O compatibility effect, then this experiment should also yield in a reliable compatibility effect. If, however, consistent S-R and R-O mappings are also necessary for obtaining the compatibility effect, then this experiment should yield no S-O compatibility effect.

Any conclusion drawn from the absence of a compatibility effect will be limited by the fact that stimulus length was task-irrelevant during the acquisition phase. However, we could not rule out, a priori, the possibility of implicit perceptual associative learning. Evidence for such learning has been previously reported (Turk-Browne et al., 2010; Zhao et al., 2013). Indeed, compared to the previous studies, the visual features employed in our experiments were much simpler and easier to identify. Furthermore, stimulus exposure in this experiment was identical with Experiment 2. One might argue that without the relevance of line lengths to task, they would simply not be noticed. But the lengths were actually easy to notice, as confirmed by the high performance accuracy in the test phase (>90%). Furthermore, if one accepts that low discriminability reduces the chance of associative learning, then one would face difficulty explaining the stronger S-O compatibility effect with *low* discriminability, relative to high discriminability, found in Experiment 2. This difficulty is averted by accepting the important role of response in learning, which is precisely the premise we aim to support. On the other hand, if one accepts the possibility of perceptual learning under difficult discriminability condition, then one has to also consider the possibility of S-O associative learning, based on implicit perceptual covariation alone, which warrants the present experiment.

Method

Participants. Twenty-three new University of Toronto undergraduate students (mean age: 22.1; 16 females) took part in this experiment.

Apparatus, stimuli, and procedure. These were identical to those in Experiments 2, with the following exceptions. First, in the acquisition phase, participants responded to target location and not target length. This modification enabled us to keep S-O mapping consistent throughout both phases of the experiment (yellow associated with short lines; blue associated with long lines). By contrast, R-O mapping was consistent only within the test phase, identical to the mapping employed in Experiments 2. Second, since discrimination difficulty is not a factor of interest in this experiment, we had to choose one discrimination difficulty. On the one hand, choosing the difficult level lead to better learning in Experiment 2. On the other hand, choosing the difficult level might reduce the chance of stimulus lengths being noticed, hence reducing the chance of S-O associative learning. We chose the medium difficulty level, by averaging the target lengths from the previous experiments (.36° and .67°, respectively, for short and long lengths). Given that both difficulty levels did result in reliable S-O compatibility effects in Experiment 2 (albeit a reduced compatibility effect in the high-discriminability condition), choosing the medium difficulty level seemed appropriate. Each participant completed 120 trials of acquisition, followed by 80 test trials.

Results and Discussion

Acquisition. Mean accuracy and speed were, respectively, 99% (SE = .3%) and 355 ms (SE = 6 ms).

Test. Accuracy data were submitted to a two-tailed within-subjects t test, with S-O compatibility as the factor. This test did not yield an effect, $t(22) = 1.10$, $p = .28$, Cohen's $d = .25$. Accuracies were comparable across the compatible (91% $\pm$ 1%) and incompatible (92% $\pm$ 1%) conditions. In addition to being statistically nonsignificant, the direction of the effect was opposite to what would be expected on the basis of a perceptual S-O associative learning.

Response time data were submitted to the same t test, which also showed no effect, $t(22) = 1.66$, $p = .108$, Cohen's $d = .35$. Response times across the compatible (548 $\pm$ 14 ms) and incompatible (558 $\pm$ 15 ms) conditions did not differ reliably, although the direction of the difference was consistent to what would be expected on the basis of a perceptual S-O associative learning. Perhaps we should not easily dismiss this nonsignificant difference (the reader who predicts this effect might even encourage a one-tailed test, which would yield the p value of .054). Two possibilities should be considered. First, this nonsignificant difference might reflect an underpowered compatibility effect driven by a perceptual associative learning. Second, it could reflect a sensorimotor (R-O) associative learning that emerged during the test phase. As demonstrated by Wolfensteller and Ruge (2011) reliable S-R-O associative learning could be formed after a dozen trials. To discriminate between the two possibilities, we compared the first and the second halves of the test phase, and found that the compatibility effect in the first half of the test phase was far from statistical significance, $t(22) = .18$, $p = .84$, Cohen's $d = .04$, whereas in the second half the effect was closer to statistical significance, $t(22) = 1.61$, $p = .110$, Cohen's $d = .34$. This pattern does not support the idea that the S-O covariation alone is sufficient for obtaining the S-O compatibility effect, and is instead consistent with the R-O learning during the test phase.

Finally, similar to Experiment 2, we also found a Simon effect; for RT data, $t(22) = 3.10$, $SE = 5.66$, $p = .005$, Cohen's $d = .63$; for accuracy data, $t(22) = 3.05$, $SE = .02$, $p = .006$, Cohen's $d = .65$. The magnitude of the Simon effect did not statistically differ from that found in Experiment 2; contrast for RT data, $F(1, 113) < 1$; for accuracy data, $F(1, 113) = 1.69$, $p = .196$, $\eta_p^2 = .015$. The similarity of effect sizes across Experiments 2 and 3 suggests that the magnitude of the Simon effect may not be sensitive to learning associations between responses and nonspatial outcomes, such as color (cf. Hommel, 2004), although this issue falls beyond the scope of our present study. In sum, the findings of Experiment 3 suggest that responses or (i.e., R-O consistency) play a role in obtaining the S-O compatibility effect.

General Discussion

Goal-directed action is possible because actors can select the learned sensory outcomes of their actions (Hommel, 2013; Shin et al., 2010). Although there is substantial empirical support for outcome-based selection, some evidence suggests that when the contribution of stimulus-based selection is substantially large, the outcome plays a smaller role in selection (Herwig et al., 2007; Herwig & Waszak, 2009; Pfister et al., 2011; Pfister & Kunde, 2013). The present study investigated the possibility that the contribution of outcome-based processes might vary as a function of the efficiency of stimulus-based action selection. Confirming this notion, we found that efficient stimulus-based response selection (i.e., direct S-R spatial mapping in Experiment 1; high stimulus discriminability in Experiment 2) reduced the effect of outcome-based processes, relative to inefficient stimulus-based response selection (i.e., inverse S-R spatial mapping in Experiment 1; low stimulus discriminability in Experiment 2). This observation suggests that when target stimulus does not give the correct response a decisive advantage over the incorrect response, the contribution of outcome-based selection is increased. Experiment 2 further suggests that it is primarily the use of R-O association that is affected by stimulus-based selection efficiency, and not R-O learning (Pfister et al., 2011). Finally, Experiment 3 suggests that purely perceptual S-O associative learning is insufficient for obtaining the S-O compatibility effect in the present study, confirming the role of response and R-O associative learning. Based on these findings we argue that reducing the efficiency of stimulus-based response selection can increase the contribution of outcome-based response selection.

The present study is not the first to report R-O associative learning in a forced-choice task. Herwig et al. (2007, Experiment 2) found a compatibility effect on accuracy. Furthermore, Pfister et al. (2011) found reliable R-O compatibility after a forced-choice acquisition phase, when the test phase required free-choice responses. The authors argued that R-O associative learning can take place regardless of whether participants encounter the outcomes during a free- or forced-choice task, but that the use of learned R-O association is more robust in the free-choice mode. Pfister and Kunde (2013) later showed that mixing free- and forced-choice responses within the same experimental block can give rise to reliable R-O compatibility effect on forced-choice trials, presumably because the free-choice trials promote an overall outcome-based mode of action that is extended to the intermixed forced-choice trials. The novel aspect of the present findings, therefore, is not in finding R-O compatibility, but in demonstrating systematic variations in R-O compatibility effect that depend on stimulus-based selection efficiency. In short, performance in the same forced-choice task could involve a higher degree of outcome-based selection, if the target stimulus does not strongly activate the correct response.

In the present study, we were not concerned with the dissociation between response activation and response selection, but with (a) whether or not processes that culminate in response selection are sensitive to features that resemble a learned R-O, and (b) whether or not sensitivity to those features varies with the ease and efficiency of stimulus-based response activation/selection. For this reason, we used the response "induction" method gauging outcome-based processing. In this method, a distractor that resembles a learned action-outcome is presented along with the target stimulus. The induction method can be contrasted with the method that involves endogenous outcome anticipation (Kunde, 2001; Pfister et al., 2010; Zwosta et al., 2013). The latter method is thought to primarily impact response selection (Paelecke & Kunde, 2007), and it often involves manipulating R-O compatibility across separate experimental blocks. As such, the block-wise manipulation of R-O compatibility would introduce an additional source of response selection inefficiency, similar to our manipulations of S-R mapping (Experiment 1) and stimulus discriminability (Experiment 2). Because we already incorporated a block-wise performance efficiency factor in each experiment, we chose to manipulate R-O compatibility without introducing a second source of block-wise performance inefficiency, which made the induction method an appropriate choice. Examining similar modulations of R-O compatibility in designs that rely on endogenously selected outcomes, therefore, represents a worthwhile avenue for future investigations.

The fact that we found our critical findings in accuracy data, and not in RT, deserves some discussion. Similar to our findings, Herwig et al. (2007, Experiment 2) also reported evidence for R-O compatibility effect in errors, without finding the effect in RT. This might be the result of a speed–accuracy trade-off, reflective of a relatively liberal decision criterion adopted by the participants (Ratcliff & Rouder, 1998). With a conservative decision criterion, more information needs to accumulate before a response is made. A conservative criterion enables participants to maintain a high mean accuracy, and the effects would likely appear in performance speed. With a liberal decision criterion, on the other hand, relatively less information needs to accumulate before a decision is made. A liberal criterion, therefore, enables maintaining fast performance, and the effect would likely appear in accuracy. This could either reflect a strategy that our participants happened to adopt or it could be a consequence of our task characteristics. The latter possibility is supported by the brevity of target exposure duration (100 ms in Experiment 1; 200 ms in Experiments 2), which might have discouraged participants from adopting a conservative criterion. In such a situation, slowing down performance would not offer additional sensory access to the target. Therefore, finding reliable S-O compatibility effect on accuracy might indicate a liberal decision criterion adopted by the participants.

We should also consider that S-O compatibility might primarily affect response activation. Assuming that response activation is not subject to the same processing limitations as response selection (Hommel, 1998a; Pashler, 1994), and that multiple responses can be activated in parallel without additional cost on performance speed (especially if participants do not adjust their speed-accuracy function in order to maintain their accuracy level), then the cost of S-O compatibility on response initiation would be negligible. A recent method by Pfister et al. (2014) demonstrated that the impact of competing actions is not confined to performance speed. Instead, activating two action intentions, simultaneously, impacts the trajectory of the executed movement, toward the unexecuted (but active) intention (cf. Tipper, Howard, & Jackson, 1997). Such modulations in the actual movements are not measured when examining RT alone. In the present study, if two responses are activated, without adjusting the speed-accuracy function, then the activation of the incorrect response is revealed only in a higher probability of actually executing the incorrect response. In short, assuming that S-O compatibility impacts response activation, and not necessarily response selection, maintaining a relatively liberal speed-accuracy function could mask the compatibility effect on performance speed. We should note that the validity of our present hypothesis of why this finding appeared in accuracy data, and not in RT data, will require further investigation.

Impact of Overall Performance Speed

Previously, research has demonstrated that slower responses yield larger R-O compatibility effect (e.g., Kunde, 2001; Kunde, Koch, & Hoffmann, 2004; Paelecke & Kunde, 2007). In Experiments 1 and 2, the modulation in the S-O compatibility effect appears to be confounded with changes in performance speed. Therefore, we tested whether or not performance speed can account for changes in the S-O compatibility effect, by reanalyzing the data from Experiments 1–2 after dividing test trials into equal bins of "fast" and "slow" responses.[4] We modified the previous mixed ANOVAs by adding performance speed (fast vs. slow) as an additional within-subject factor. For Experiment 1, analysis of accuracy revealed a two-way interaction between speed and S-O compatibility, $F(1, 44) = 11.45$, $p = .002$, $\eta_p^2 = .206$, and a three-way interaction between speed, S-O compatibility, and S-R spatial mapping, $F(1, 44) = 4.50$, $p = .04$, $\eta_p^2 = .093$. As illustrated in Figure 5, the largest S-O compatibility effect appeared with the fast responses in the inverse S-R mapping condition. Analysis of RT, resulted in a two-way interaction between speed and S-R mapping, $F(1, 44) = 22.53$, $p < .001$, $\eta_p^2 = .339$, and only a marginal two-way interaction between speed and S-O compatibility, $F(1, 44) = 4.01$, $p = .052$, $\eta_p^2 = .083$. In the RT data, with slower performance, there was a nonsignificant trend consistent with the S-O compatibility effect (M $\pm$ *SE* = 10 $\pm$ 5 ms, $p = .071$), but there was clearly no effect with faster performance (M $\pm$ *SE* = -1 ± 2 ms, $p = .627$).

For Experiment 2, analysis of accuracy revealed a main effect of S-O compatibility, $F(1, 90) = 29.66$, $p < .001$, $\eta_p^2 = .248$, a two-way interaction between stimulus discriminability and S-O compatibility, $F(1, 90) = 5.24$, $p = .024$, $\eta_p^2 = .055$, and a two-way interaction between speed and stimulus discriminability, $F(1, 90) = 31.58$, $p < .001$, $\eta_p^2 = .260$. As illustrated in Figure 6, the effect of stimulus discriminability was more pronounced on slow trials. Most important, we did not find an interaction between performance speed and S-O compatibility, $F(1, 90) = 1.78$, $p = .185$, $\eta_p^2 = .019$. Analysis of RT, resulted in a main effect of S-O compatibility, $F(1, 90) = 3.99$, $p = .049$, $\eta_p^2 = .042$), a two-way interaction between speed and stimulus discriminability, $F(1, 90) = 67.63$, $p < .001$, $\eta_p^2 = .429$. Again, we did not find an interaction between performance speed and S-O compatibility, $F(1, 90) < 1$. To summarize the analyses, reduction in performance speed either did not modulate S-O compatibility effect at all (Experiment 2) or it reduced S-O compatibility effect (Experiment 1). These results suggest that performance speed alone cannot predict the participants' sensitivity to response outcomes. The results further suggest that S-O compatibility affected the earlier processes of response activation, rather than the later processes of response selection (Paelecke & Kunde, 2007).

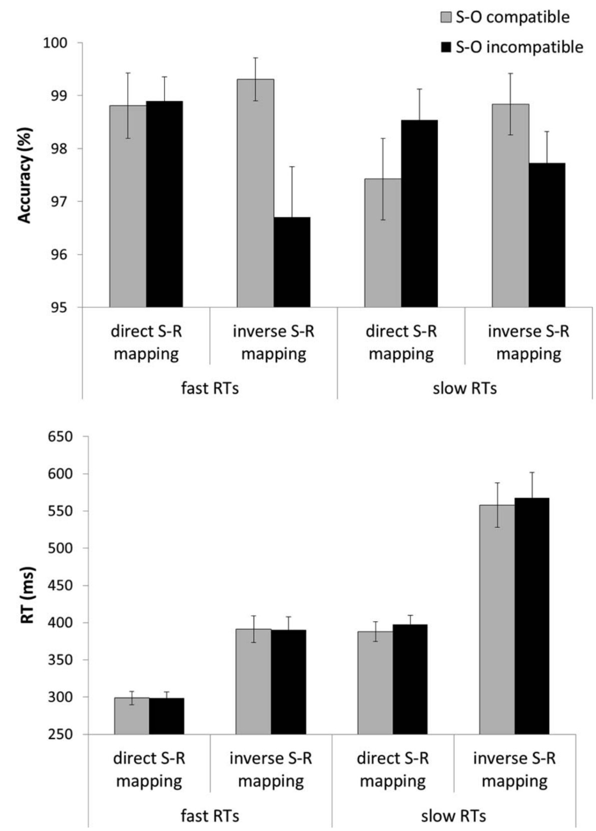

Figure 5. Data from Experiment 1, graphed as a function of performance speed, spatial stimulus–response (S-R) mapping, and stimulus–outcome (S-O) compatibility. Error bars indicate standard errors.

[4] Because of the small number of test trials (80), we divided trials based on speed only into two bins. Considering the exclusion of error trials and outliers in RT analyses, this division resulted in [a maximum of] 20 trials per condition, per participant.

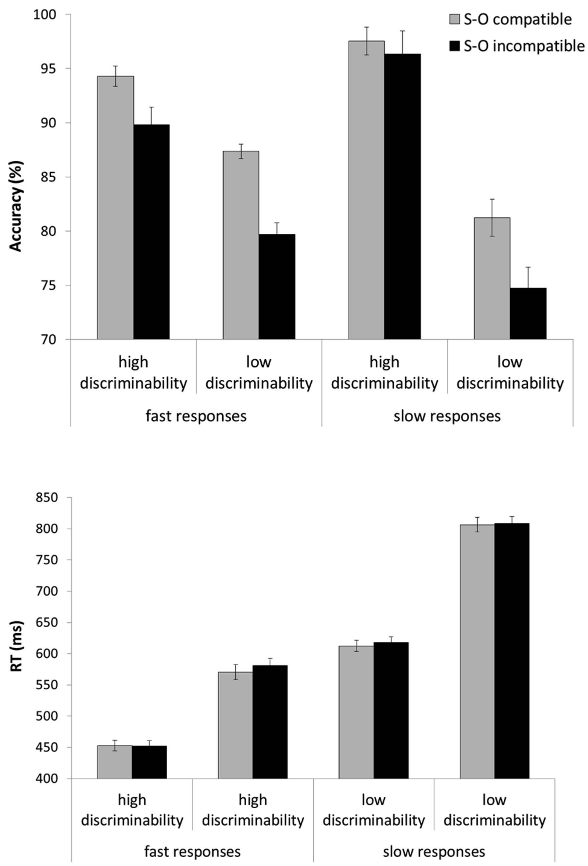

Figure 6. Data from Experiment 2, graphed as a function of performance speed, stimulus discriminability, and stimulus–outcome (S-O) compatibility. Error bars indicate standard errors.

Response–Outcome Versus Stimulus–Outcome Learning

We interpret the compatibility effects as mediated by the response selection processes rather than learned associations between targets and outcomes. Purely perceptual associations are unlikely to be the cause of the present S-O compatibility effects. First, it has been shown that stimulus–stimulus associative learning requires the two stimuli to be presented in close spatiotemporal proximity during the acquisition phase (Gozli et al., 2014; Zmigrod & Hommel, 2010). In our experiment, targets were presented briefly (100 ms in Experiment 1; 200 ms in Experiments 2–3) and the outcomes were never presented at the same time with the target. Target stimuli and color outcomes, furthermore, were never presented at the same location during the acquisition phase, which prevents them from being bound into a single perceptual representation (Hommel, 1998b; Kahneman, Treisman, & Gibbs, 1992). Second, it is difficult to explain how perceptual associative learning could be modulated by the stimulus-driven response selection efficiency. In Experiment 1, for instance, perceptual items were identical in both direct and inverse mapping conditions. Left/right targets were followed by centrally presented blue/yellow colors. Despite the perceptual similarity, the S-O compatibility effect was larger in the inverse (i.e., inefficient) condition, which can only be accounted for by the difference in response selection efficiency. Third, Experiment 3 demonstrated that maintaining S-O mapping alone does not give rise to the compatibility effect, further arguing against a purely perceptual associative learning.

Stimulus-Based Versus Outcome-Based Processes

The present findings are relevant with regard to the theoretical distinction between stimulus- and outcome-based modes of action. Variations in the contributions of the outcome-based selection as a function of stimulus-based selection favors the view that the two processes concurrently contribute to action selection. Some previous research has made the assumption that the two modes of response selection can be studied, respectively, under forced-choice (stimulus-based) and free-choice (outcome-based) conditions. Challenging this assumption, Janczyk, Dambacher, et al. (2015) and Janczyk, Nolden, and Jolicoeur (2015) recently showed that forced- and free-choice actions might be identical in terms of response selection. Using the psychological refractory period paradigm (Pashler, 1994), the authors showed that the two response types interacts underadditively with the effect of temporal overlap between the two tasks (Janczyk, Dambacher, et al., 2015). This finding suggests that the performance benefit of the forced-choice response over the free-choice response is not related to the refractory period. That is to say, the difference does not reflect an advantage in response selection, but most likely an advantage in perception and/or response activation. In a similar vein, the increase in RT in a dual-task condition (over a single-task) caused by a free-choice task was found to be statistically indistinguishable from the interference caused by a forced-choice task (Janczyk, Nolden, & Jolicoeur, 2015). Again, this finding suggests that difference between free- and forced-choice conditions are not due to differences in response selection, but the perceptual and response-activation processes that precede response selection.

The present study could be speculatively discussed in relation to a finding reported by Melcher, Weidema, Eenshuistra, Hommel, and Gruber (2008) and Melcher et al. (2013), with regard to the difference between left- and right-hand responses and ideomotor learning. Melcher et al. found, in right-handed participants, stronger evidence of R-O associative learning for left-hand responses, compared to right-hand responses. Following an acquisition phase, the sensory outcome associated with the left hand was more effective in eliciting the neural response associated with the motor movement. The reason, the authors speculated, might be due to the difference in proficiency in performing left- and right-hand actions. Relatively better motor skill (i.e., the dominant hand), accordingly, would reduce the processing weight given to task-irrelevant sensory features, such as arbitrary visual R-O. Relatively worse motor skills (i.e., the nondominant hand), in comparison, would increase the processing weight given to task-irrelevant sensory features. A similar reasoning could be applied to our findings regarding the role of task efficiency in determining the contribution of ideomotor (outcome-based) processes.

Dimensional Weighting

In situations where the actor is already equipped with a rich knowledge of R-O contingencies, learning novel contingencies is beneficial only when the already-existing knowledge does not allow efficient performance. As a consequence, novel sensory outcomes might receive a processing disadvantage, especially when they belong to a task-irrelevant perceptual dimension. For instance, Herwig et al. (2007) used auditory outcomes, in a primarily visual task. It is possible that dimensional weighting in their stimulus-based condition reduced the processing weight attributed to auditory stimuli. Reduced processing weight would decrease the likelihood of the features being integrated into the event representation (Hommel, 1998b; Memelink & Hommel, 2013). Consistent with the differential weighting account, Pfister and Kunde (2013) found that when the target stimuli and the outcome stimuli are both spatially defined, R-O compatibility effects are larger (Pfister & Kunde, 2013, Experiment 1), relative to when the target stimuli and the outcome stimuli are defined, respectively, based on color and location (Pfister & Kunde, 2013, Experiment 2). Furthermore, Janczyk et al. (2012) found larger evidence for R-O association in a forced-choice task, compared to a free-choice task, with stimuli and responses that were spatially defined. These findings are consistent with the role of dimensional task-relevance in R-O associative learning (Memelink & Hommel, 2013).

An important question for future research is whether maintaining S-R consistency impacts the R-O association. If so, removing the target stimuli during the test phase would changes the way in which responses are represented. That is, the same keypress might be coded as a different response without its corresponding target stimulus, which means it would not activate the same sensory outcome (Wolfensteller & Ruge, 2011; see also, Kühn & Brass, 2010; Kühn, Elsner, Prinz, & Brass, 2009). Some evidence suggests that, when R-O association varies, participants can rely on the target stimuli to determine which R-O association applies. Pfister et al., (2010) used a design in which responses and outcomes were spatially compatible or incompatible, and that compatibility varied on a trial-to-trial basis. At the beginning of each trial, a cue indicated the R-O mapping for that trial. The authors found a compatibility effect, even though compatibility was randomized (see also, Zwosta et al., 2013). Assuming that (a) the sensory outcomes are part of response representation, and (b) sensory outcomes of a given response set can vary based on a given stimulus, it follows that response representation can vary based on the given stimulus.

Conclusion

We argue against a strong dissociation between the two modes of action selection (stimulus-based vs. outcome-based). Our findings suggest that the contribution of outcome-based selection can vary continuously depending on the task. Contrary to previous studies that compared forced-choice and free-choice conditions, we showed that the contribution of outcome-based selection can change depending on the efficiency of stimulus-based response selection. Described in terms of response uncertainty, when the target stimulus alone decisively diminishes response uncertainty, outcome-based processes might contribute to a lesser extent to selection. By contrast, when response uncertainty remains high despite the target stimulus, then other sources of information, namely learned sensory action-outcomes, might be recruited more robustly to reduce uncertainty. Hence, although both selection mechanisms can work in parallel, their relative contribution can be sensitive to each other.

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